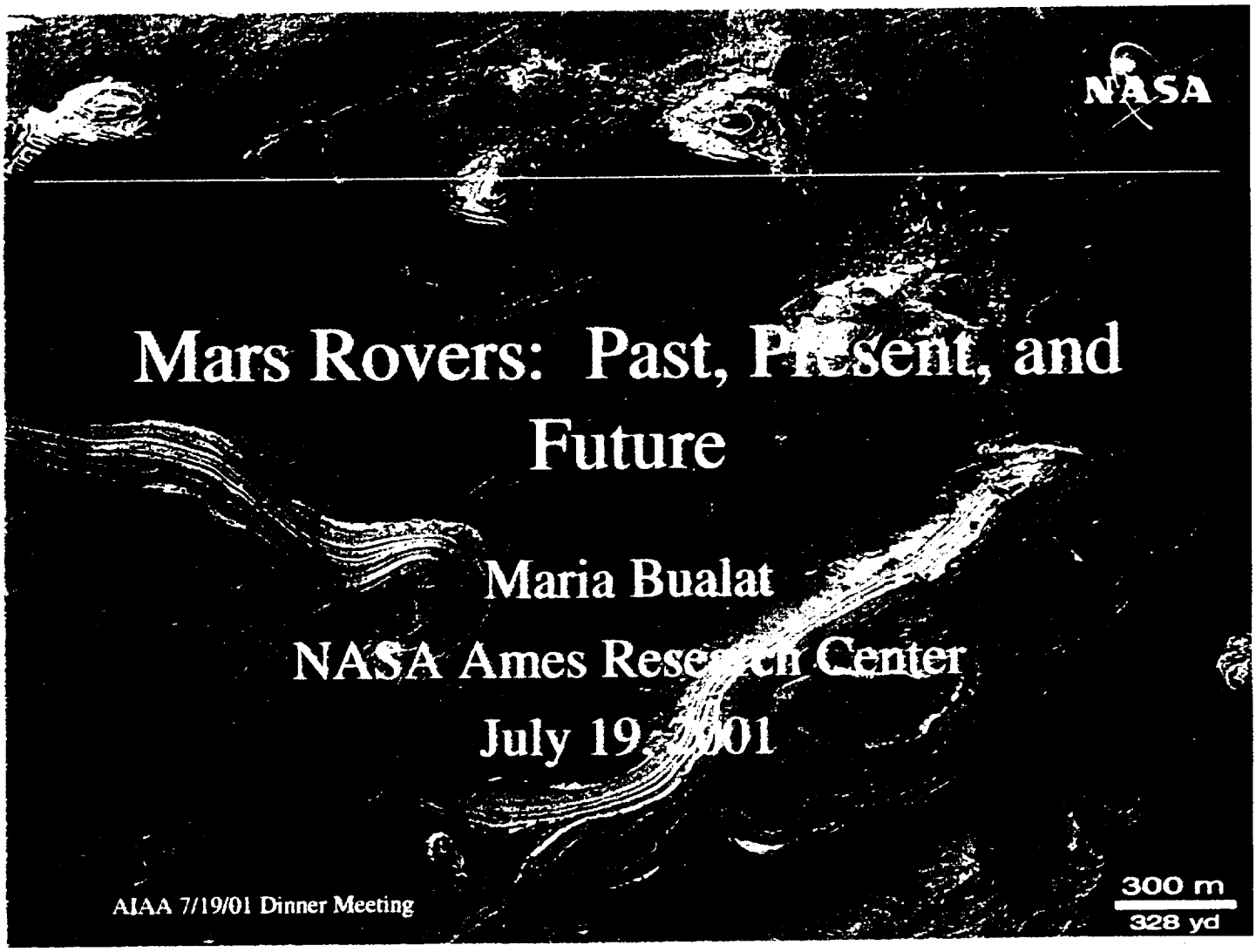
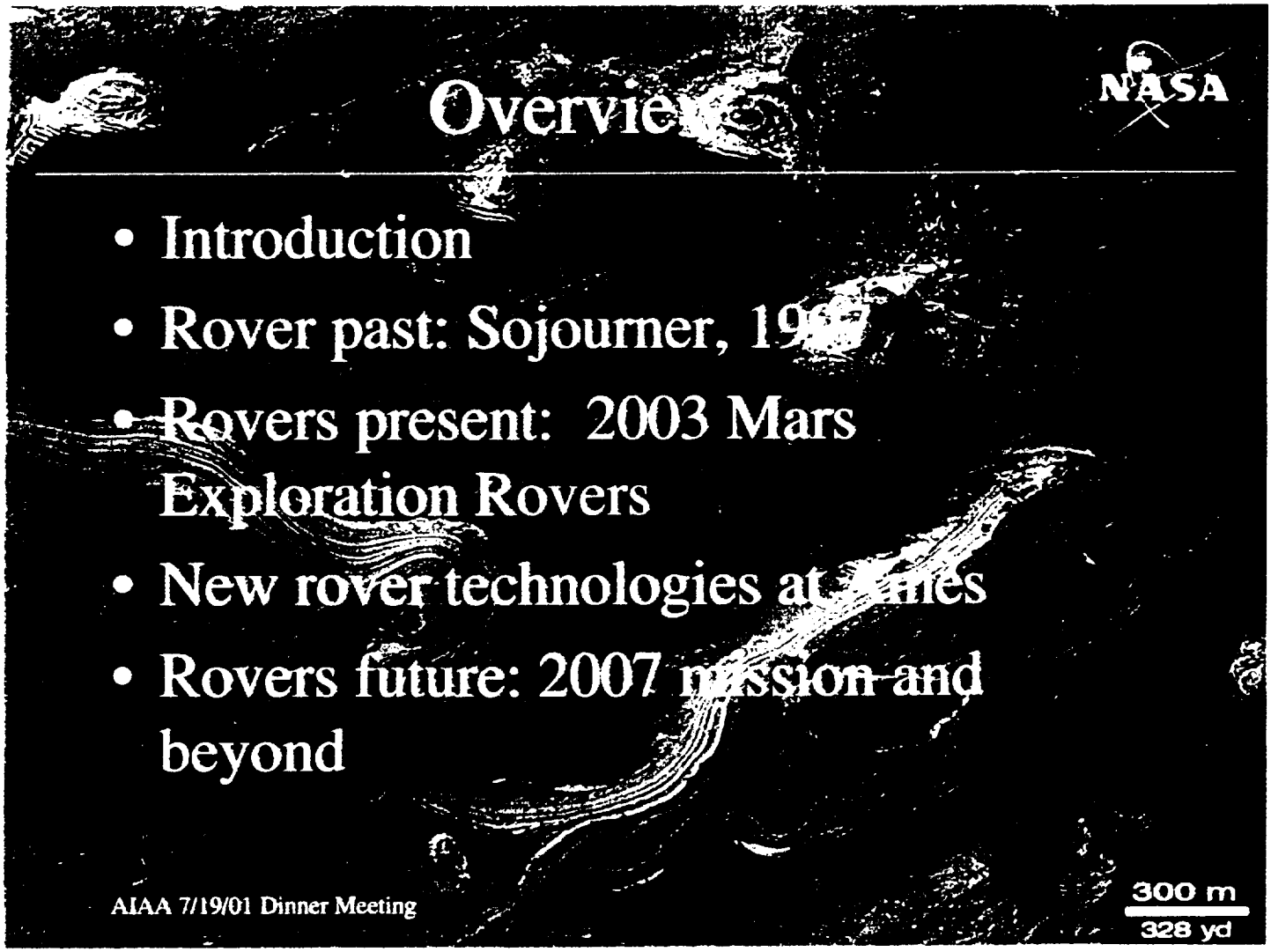

NASA
Mars Rovers: Past, Present, and Future
Maria Bualat
NASA Ames Research Center
July 19, 2001
AIAA 7/19/01 Dinner Meeting
300 m
328 yd


Overview
NASA
• Introduction
• Rover past: Sojourner, 19
• Rovers present: 2003 Mars Exploration Rovers
• New rover technologies at
• Rovers future: 2007 mission and beyond
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328 yd

Introduction

NASA

Why is Mars interesting?

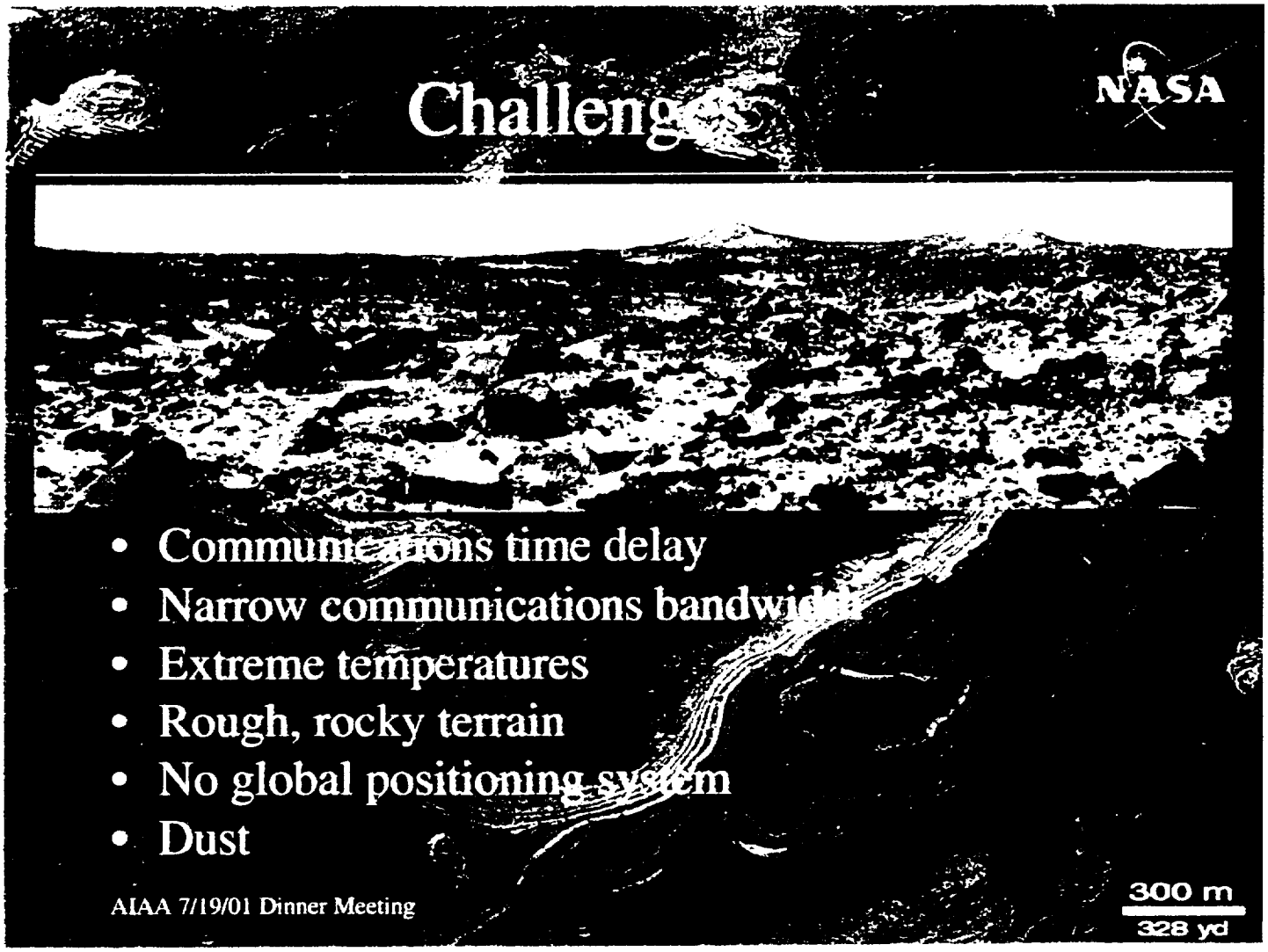
- Most Earth-like planet
- May once have had/still have liquid water and thus life
- May be possible to colonize

NASA's Mars Exploration Strategy:

Follow the water

Water is key because almost everywhere we find water on Earth, we find life.

300 m
328 yd


Challenges
NASA
• Communications time delay
• Narrow communications bandwidth
• Extreme temperatures
• Rough, rocky terrain
• No global positioning system
• Dust
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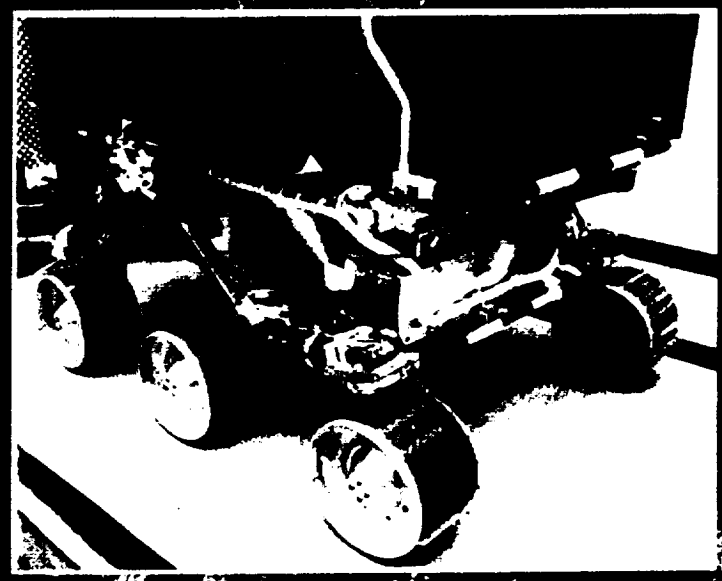
328 yd

Sojourner Rover Specs

NASA

- 13cm (~5in) wheel diameter
- Rocker-bogey chassis
- Top speed: .6m/min
- .22 m^2 solar panel providing peak of 16W
- With batteries, peak available power of 30W
- Normal driving power requirement is 10W
- 80C85 CPU, at 100Kips
- 176K of PROM and 576K of RAM



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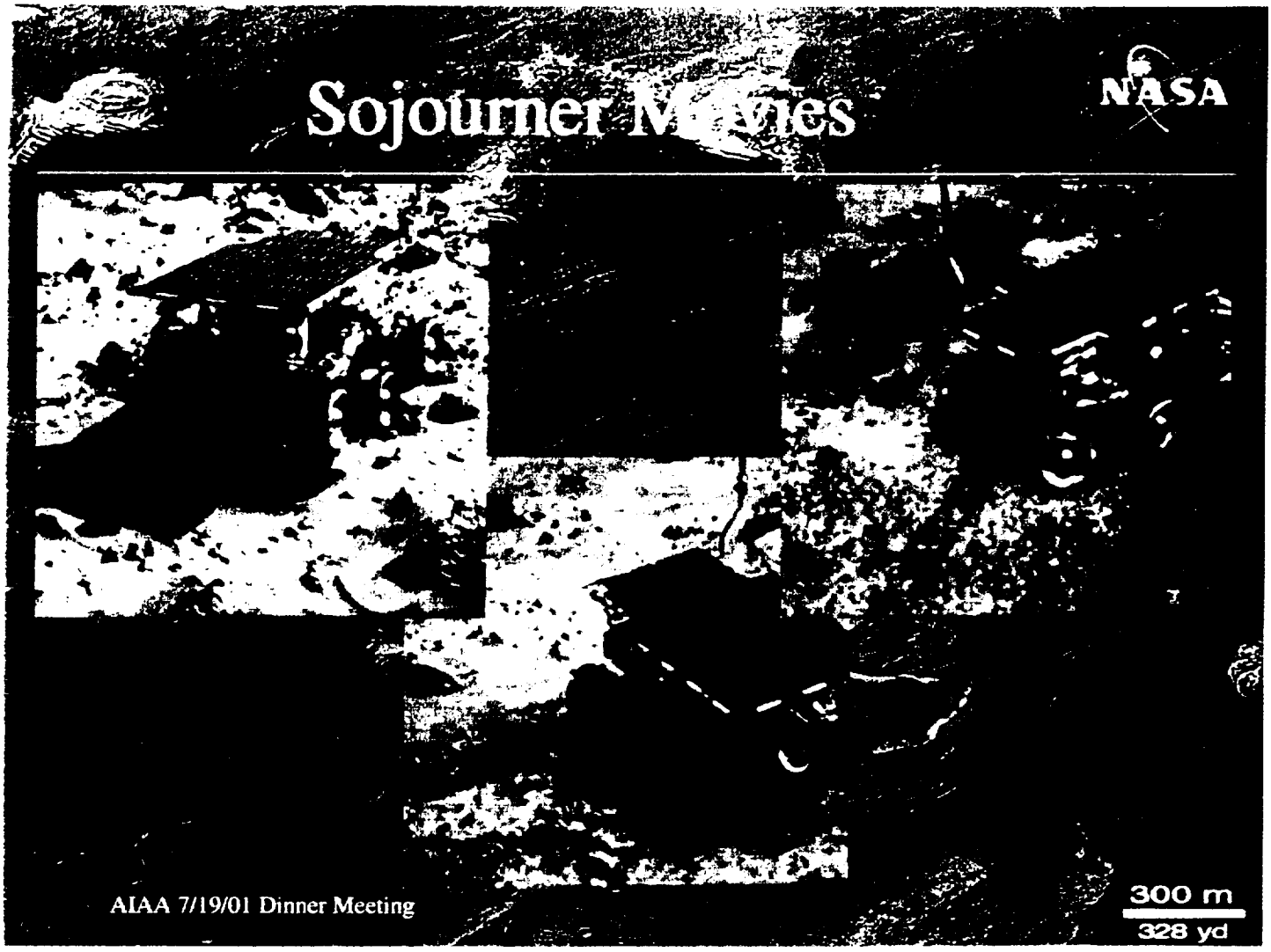
Sojourner Instruments

- Navigational:
  - front viewing stereo pair of cameras
  - laser striping system
  - gyro
  - corrections made using lander imager
- Scientific:
  - Alpha Proton X-Ray Spectrometer (APXS)

300 m
328 yd


Sojourner M ies
NASA
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Pathfinder Mission Highlights

NASA

- Launched on December 4, 1996
- 7-month cruise to Mars with [illegible] trajectory-correction maneuvers
- Landed at 9:57 a.m. PDT on July 4, 1997
  - Bounced at least 15 times up to 12 m high
- Sojourner driven down the ramp on sol 2
- Primary mission: 8 sols
- Total mission: 83 sols

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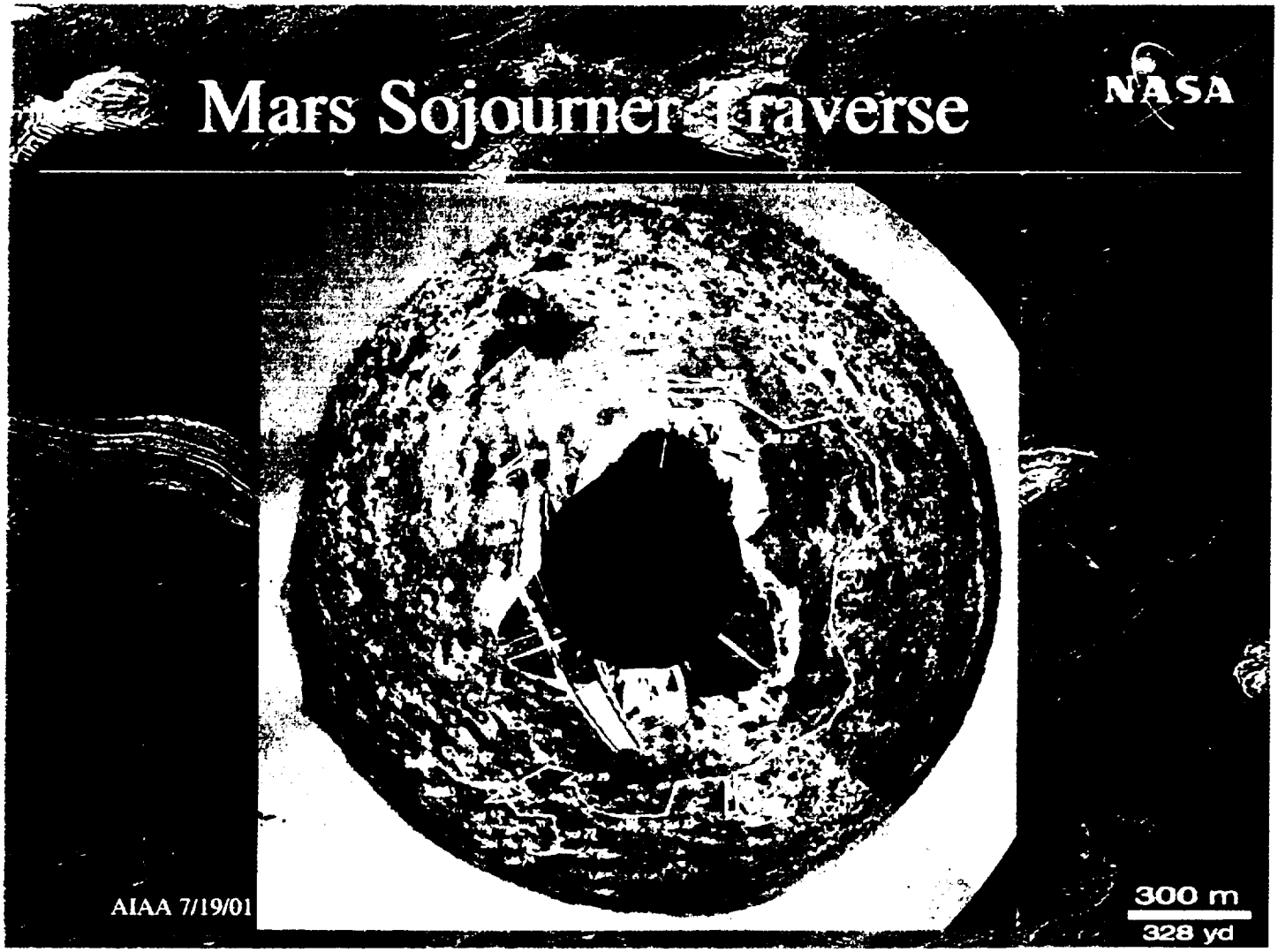
328 yd

More Highlights

- Sojourner traversed 100m around the lander
- Pathfinder returned over 16,000 lander images and 550 rover images
- Sojourner performed 16 chemical analyses of rocks and soil

328 yd


Mars Sojourner Traverse
NASA
AIAA 7/19/01
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328 yd

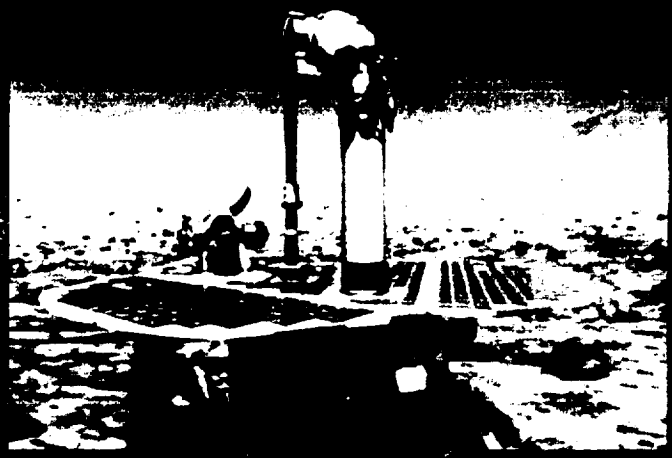
2003 Mars Exploration Rover (MER)

NASA

- Size:
  - 1.2 meters high
  - 150 kilograms
- Mobility
  - Top speed: 5 cm/s (~1 mph)
  - Capable of 100 m/day
  - Expected traverse ~1km
  - Rover/lander Communication via orbiter and direct-to-earth (DTE)
- Lifetime
  - Primary mission: 90 sols

300 m
328 yd

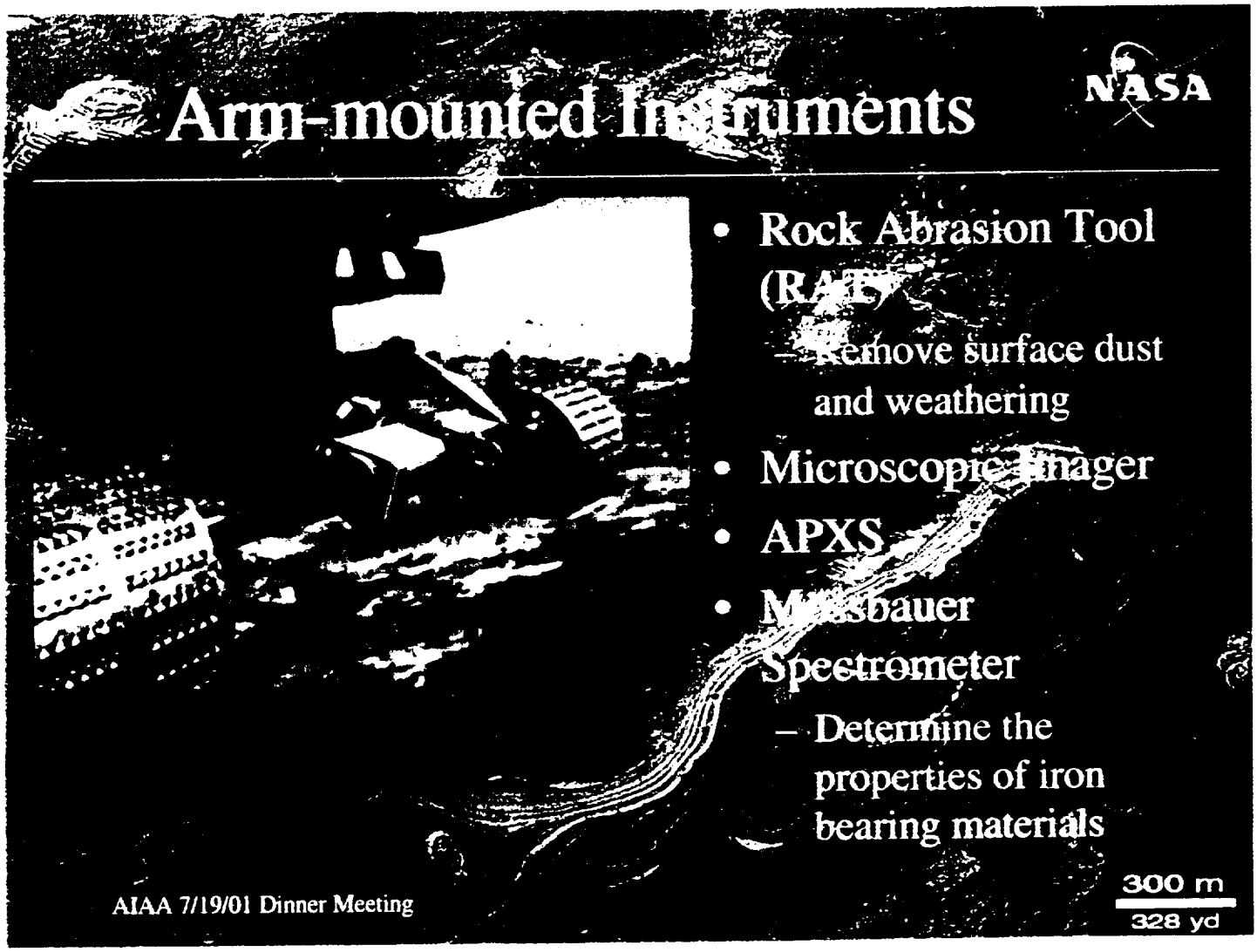
Mast-mounted Instruments



- Pancam
  - Provides high spatial resolution on the morphology of the landing site
- Mini-Thermal Emission Spectrometer (Mini-TES)
  - Obtains mineralogical information for rocks and soils surrounding the rover
  - Capable of detecting silicates, carbonates, sulfates, phosphates, oxides, and hydroxides

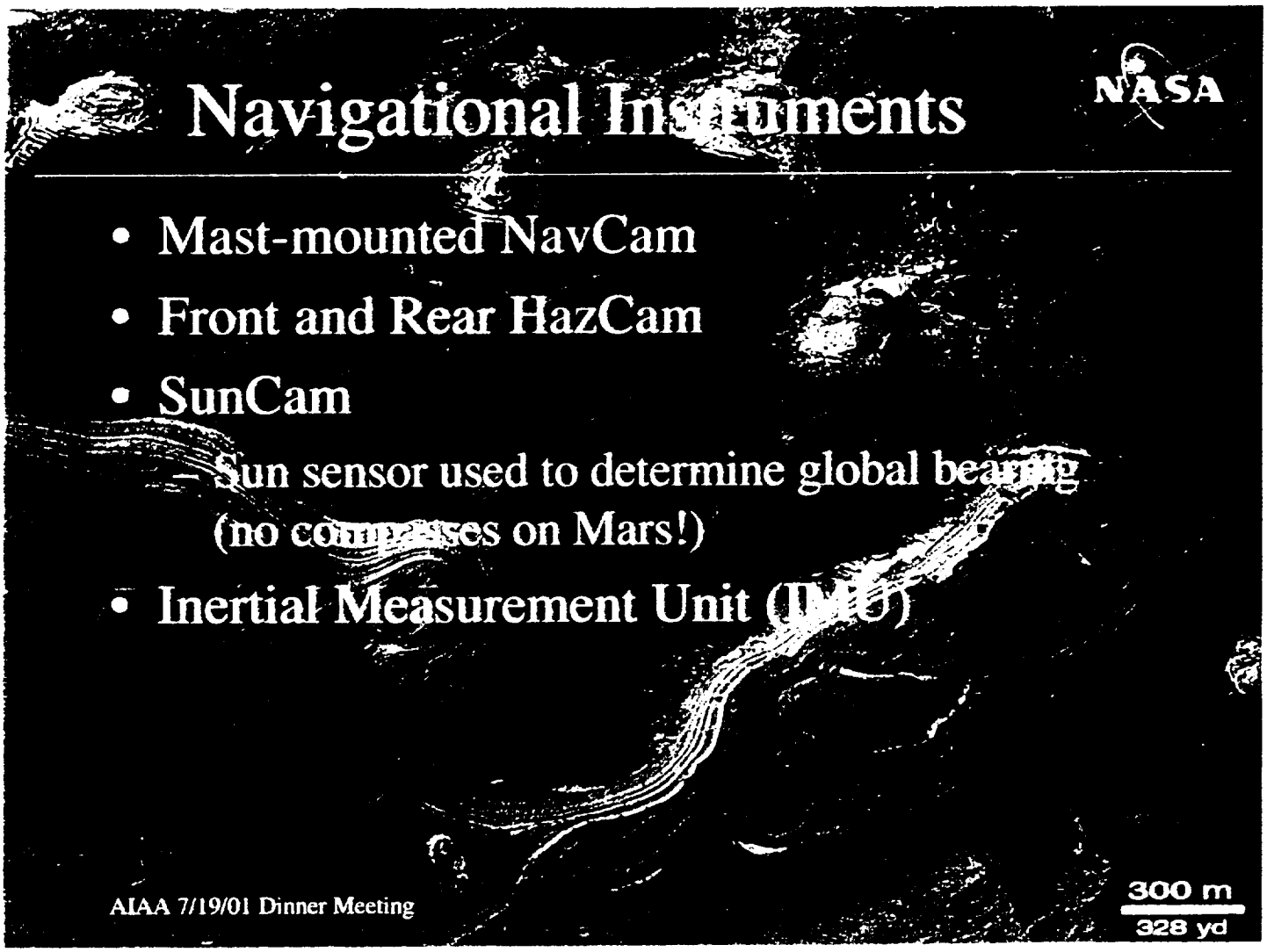
300 m
328 yd

Arm-mounted Instruments



- Rock Abrasion Tool (RAT)
  - Remove surface dust and weathering
- Microscopic Imager
- APXS
- Mössbauer Spectrometer
  - Determine the properties of iron bearing materials

300 m
328 yd


Navigational Instruments
NASA
• Mast-mounted NavCam
• Front and Rear HazCam
• SunCam
— Sun sensor used to determine global bearing
(no compasses on Mars!)
• Inertial Measurement Unit (IMU)
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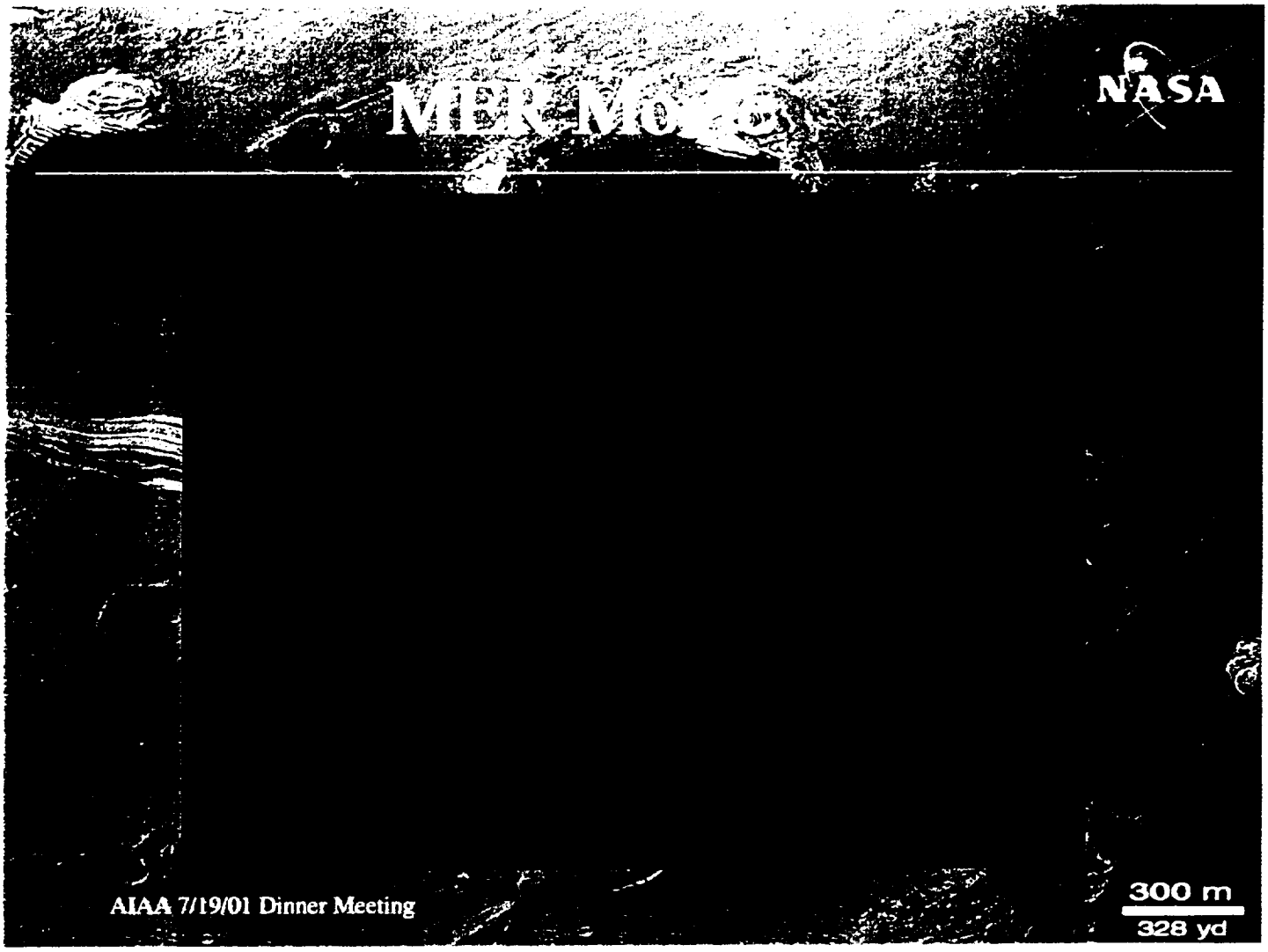
MER-MO
NASA
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300 m
328 yd

"Athena" Rover (2003) Prototypes

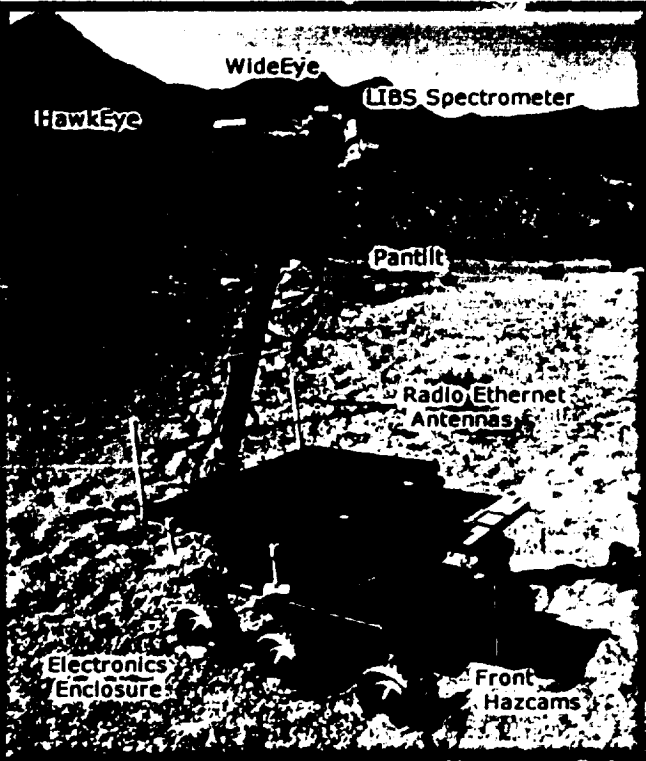
NASA

- Size: (13/7 Sojourner)
  - 1.6 meters high (K9 camera)
- Instruments
  - Athena package analogues
- Used for field testing and development at JPL (FIDO, Rocky8), Ames (K9)

300 m
328 yd

K9 Rover

NASA



- Prototype of Mars rover
- Low power electronics
- Subsystems can be powered on/off
- CPU: 166 MHz mobile Pentium MMX

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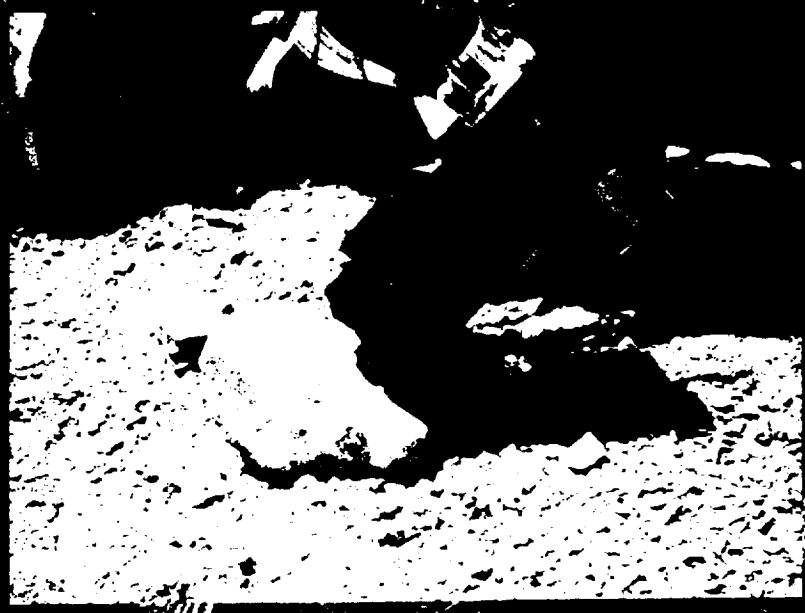
328 yd

K9 Instruments

NASA

- High-resolution color cameras
- Near-Infrared Spectrometer
- Raman Spectrometer
- Camera HAnd lens MicroscoPe (CHAMP)



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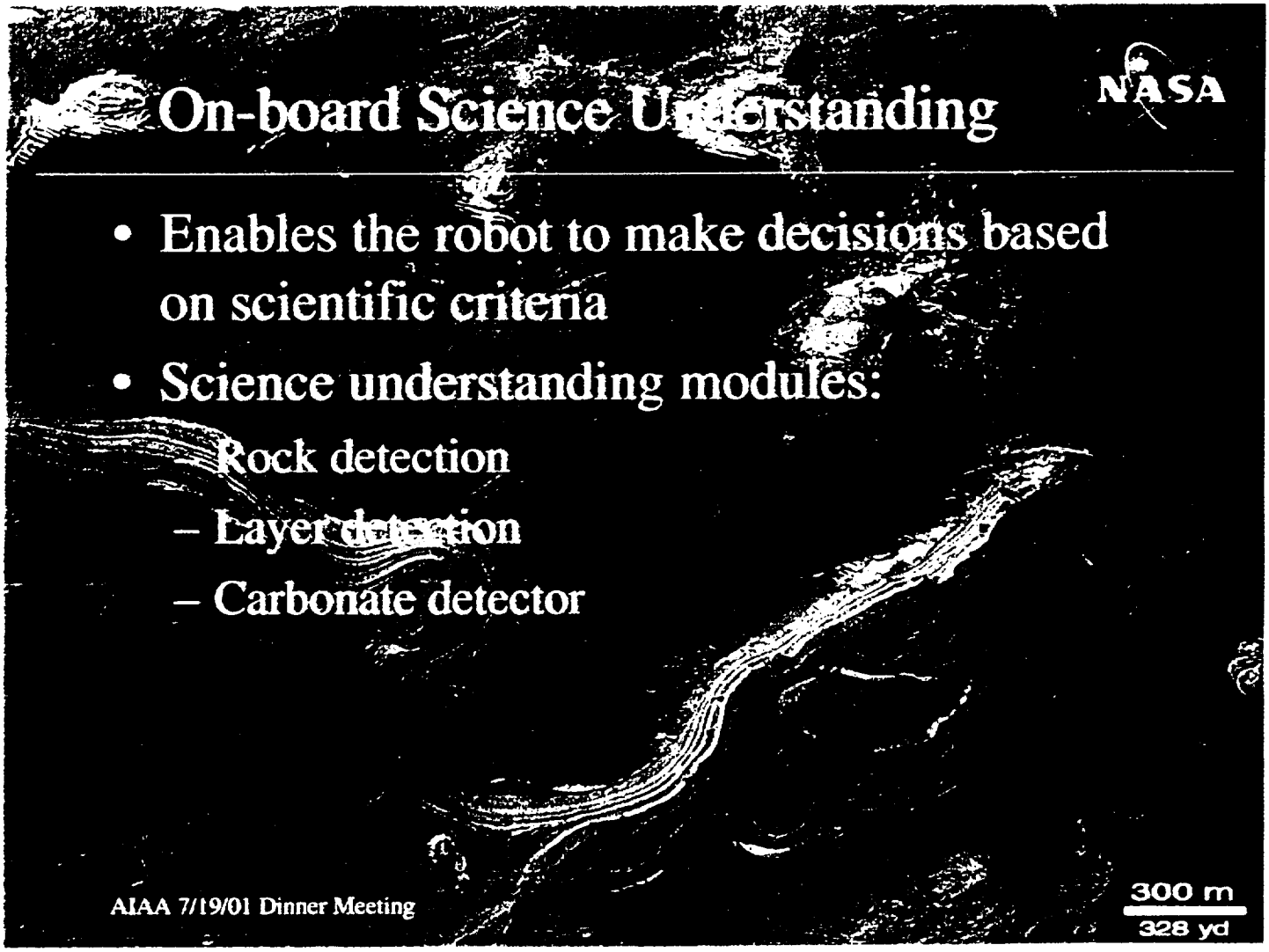
On-board Science Understanding
NASA
• Enables the robot to make decisions based on scientific criteria
• Science understanding modules:
– Rock detection
– Layer detection
– Carbonate detector
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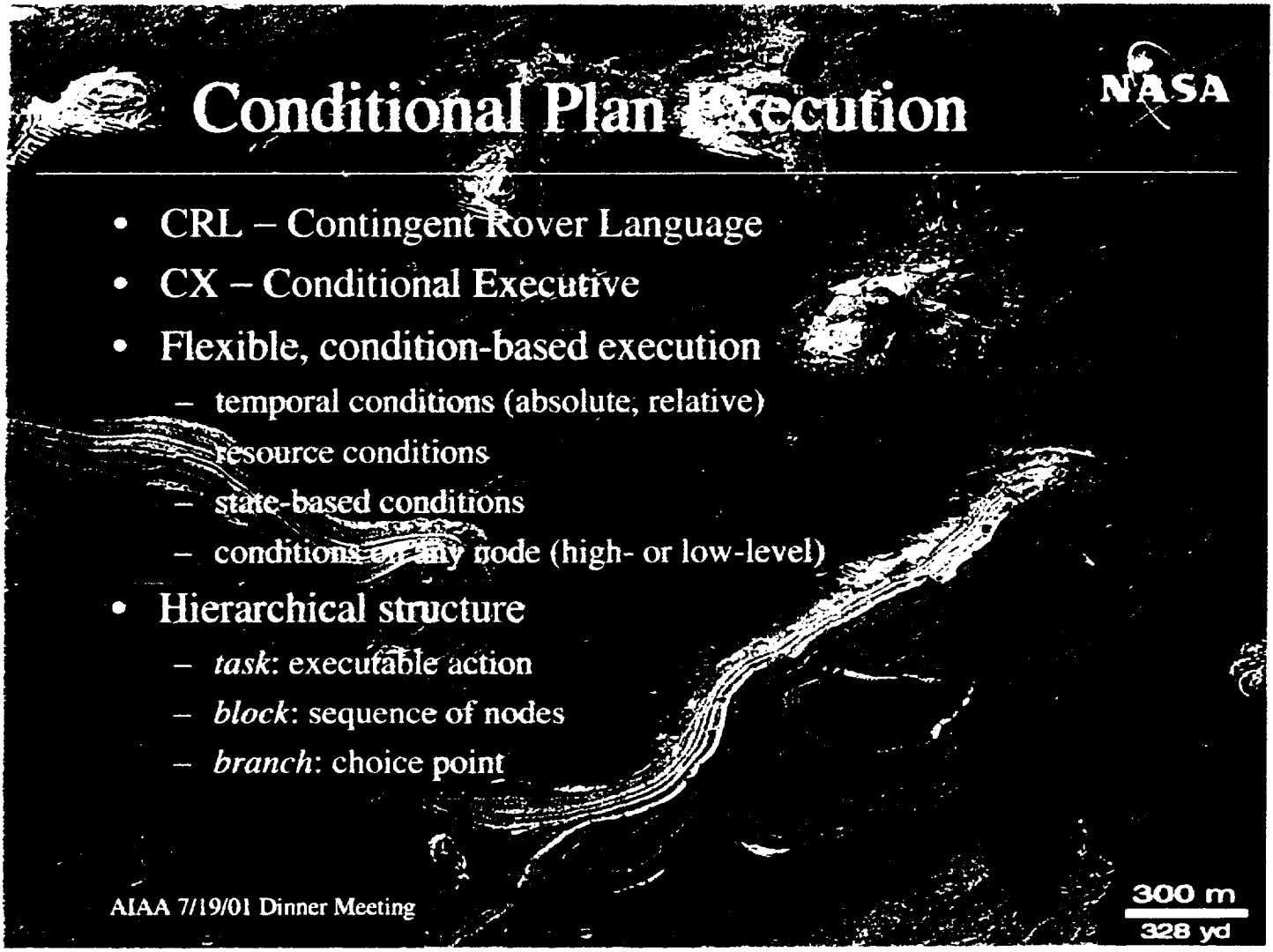
300 m
328 yd


Conditional Plan Execution
NASA
• CRL – Contingent Rover Language
• CX – Conditional Executive
• Flexible, condition-based execution
– temporal conditions (absolute, relative)
– resource conditions
– state-based conditions
– conditions on any node (high- or low-level)
• Hierarchical structure
– *task*: executable action
– *block*: sequence of nodes
– *branch*: choice point
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328 yd

Visual Servoing

- Visually tracks a target and drives to it
- Does not require end position information, only needs to know camera parameters and pan and tilt angles

300 m
328 yd

Viz - visualization tool

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300 m
328 yd

Visualization (cont.)

NASA

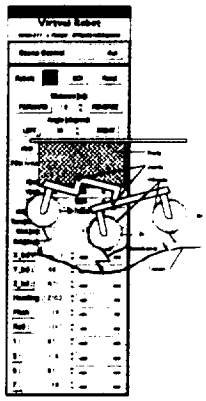
- Stereo pipeline uses rover stereo images to create terrain models
- Viz gives scientists a better understanding of context and scale
- Provides measuring tools and markers
- Valuable tool for science planning using simulator, VirtualRobot
- Can run command sequences through the simulator to verify correctness

300 m
328 yd

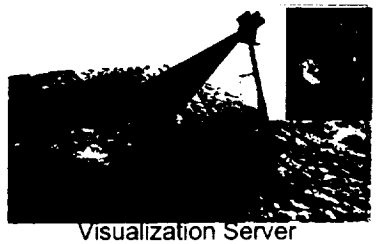
Ground Operations: VIPER

NASA

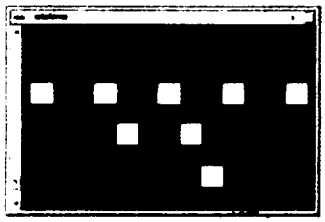
CRL Plan



Kinematic Simulator
(VirtualRobot)



Visualization Server
(VIZ)



Conditional Executive

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300 m
328 yd

Field Testing

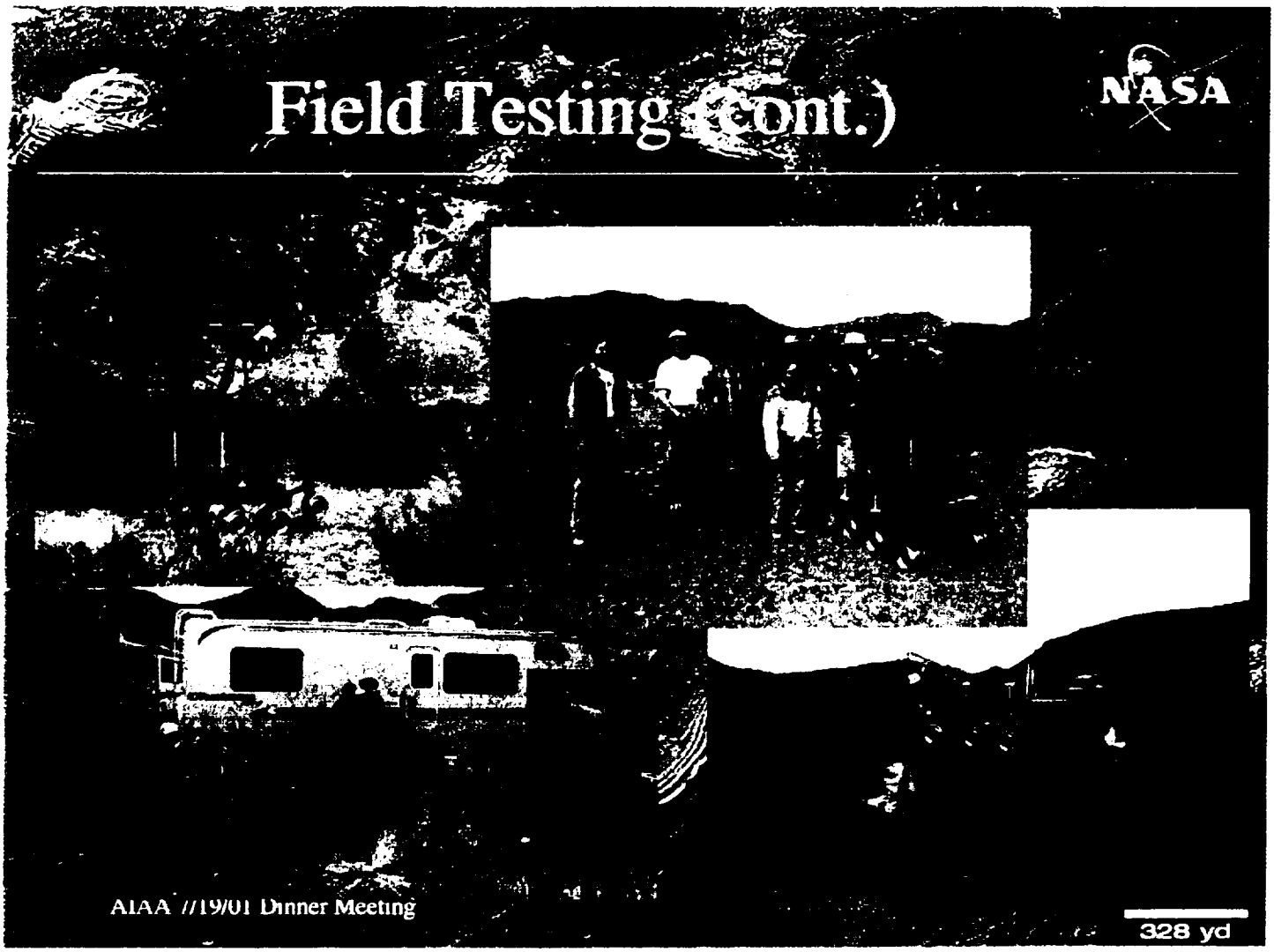
NASA

- Blind field experiments:
  - Deploy a rover in a Mars analogue field site
  - Science team in mission control not told location
  - Given only data returned by the rover, team must characterize the site
- Test and demonstrate autonomy technologies and operation scenarios
- Train science team members

300 m
328 yd

Field Testing (cont.)

NASA



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328 yd

Mars 2007

NASA

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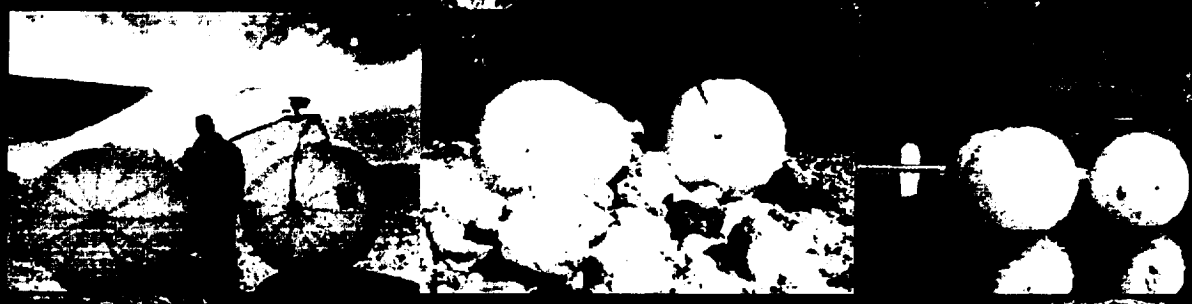
300 m
328 yd

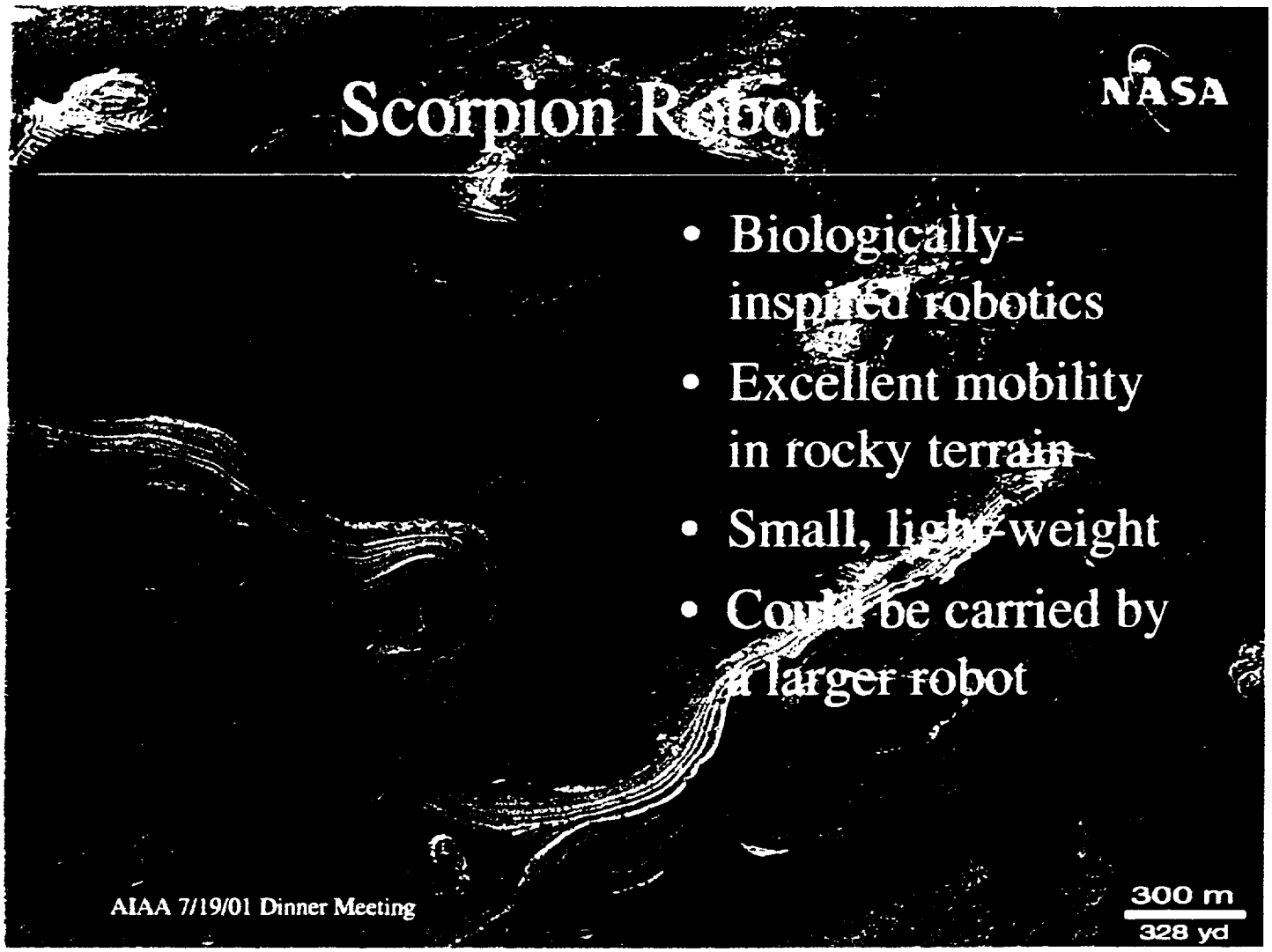
Inflatable Rover

NASA



- Light-weight, small package for launch, wheels expand on landing
- Large wheels allow the rover to go right over large obstacles and the travel at higher speeds, ~1m/s (2.2 mph)

300 m
328 yd


Scorpion Robot
NASA
• Biologically-inspired robotics
• Excellent mobility in rocky terrain
• Small, light-weight
• Could be carried by a larger robot
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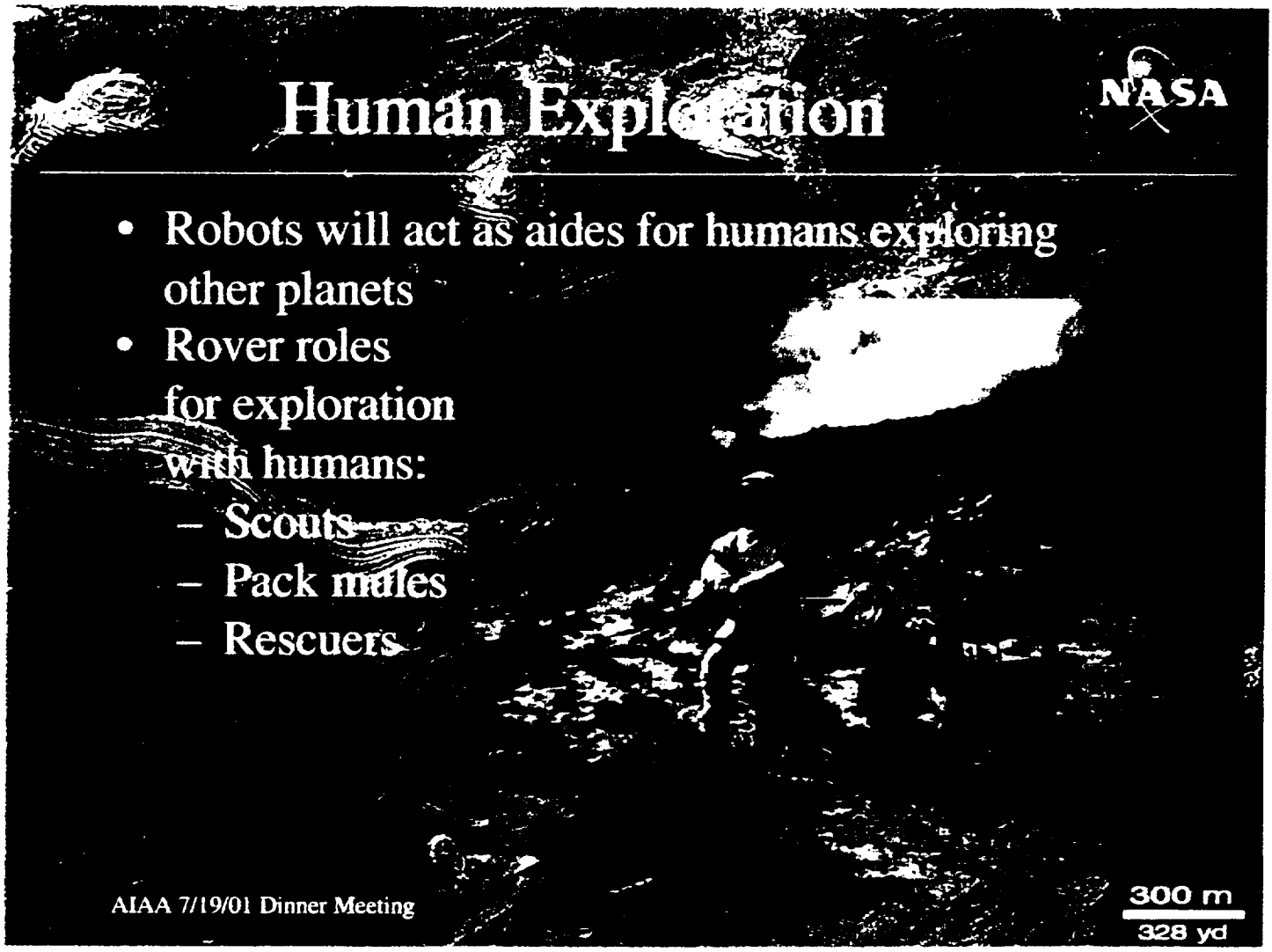
300 m
328 yd


Human Exploration
NASA
• Robots will act as aides for humans exploring other planets
• Rover roles for exploration with humans:
– Scouts
– Pack mules
– Rescuers
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300 m
328 yd